Mazak Laser Optimization

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Starflex Fabrication:
Mazak Laser Optimization

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Kennesaw State University

Fall 2019
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Executive Summary

Starflex Fabrication is a custom metal fabrication company located in College Park, Georgia. They specialize in make-to-order metal fabrications for various customers around the Atlanta area. The primary cutting machine is the Mazak laser, and Team Flex was brought in to optimize its processes.

After completing a video time study, several areas were identified for improvement, including the loading, unloading of metal sheets from the laser bed, and the cleaning and maintenance of the Mazak laser. These areas were examined by studying the industry standards, and comparing them to alternative, less costly methods.

- **Loading** - a design of a column mounted jib crane with a sheet vacuum lifter with space for increased shelving was created, and analyzed
- **Unloading** - the complete Mazak load/unload cell was compared to a single/double/triple forklift attachment
- **Cleaning of the laser** -
  - A slat cleaning machine was compared to the addition of an air chisel along with steel brushes.
  - A study of a protective chemical coating to improve the lifespan of slats was examined.
  - A system of a rotating laser lens housing was examined.

All suggestions were evaluated based on cost for implementation, and the increase of machine throughput. The suggested solutions for year one were to implement improvements in the cleaning tools, and addition of the forklift attachment to improve the unloading time. The suggested solutions for future years are the use of a rotating laser lens housing, and the loading design as they will have benefits beyond the initial costs.
Chapter 1: Problem Statement

1.1 Introduction

StarFlex Fabrication manufactures a variety of aluminum, and steel components, tools, and containers. The manufacturing process involves cutting, machining, deburring, cleaning, welding, powder coating, and packaging. The primary machine used in the cutting process is the Mazak Super Turbo x510. The Mazak uses a 4,000 watt laser for cutting through various metal sheets weighing up to 500 pounds. The cutting process requires loading, and unloading the machine, bi-weekly debris removal, and occasional cleaning of the machine lens, which are currently done manually by an operator. Starflex would like to reduce change over time, increase throughput, and reduce waste by maximizing material, and eliminating NVA (non-value-added) activities during production.

1.2 Objective Areas

1.2.1 Load & Unload Process

The Mazak Laser is the most important machine in the factory, and can be the difference between an efficient day or excessive downtime. After several observations, the loading, and unloading of the laser bed became a focus. After the job is completed, the machine bed is unloaded by hand or using a forklift to clear heavier pieces. However, the unloading process is taking an average of 6½ minutes longer than the loading process. During these processes, the machine cannot be used, and daily production is reduced.
1.2.2 Cleaning & Maintenance

Another key area of NVA during the machine’s process was the routine maintenance required to maintain the Mazak. Team Flex looked to reduce the cleaning time for the laser bed, and the laser lens. The current process for cleaning the machine bed takes an average of 2½ hours per week, and is done using non-standard tools leading to degradation of slats. The slats are also unprotected against buildup of debris which can improve their lifespan. The laser lens on the machine will fog after repeated use, however, this occurs randomly with no clear mean-time to failure. When this happens, the lens must be removed, and cleaned for several minutes before restarting the laser.

1.2.3 Manufacturing Layout.

An area the team investigated was the current manufacturing systems, and shop layout at Starflex fabrications. A Flexible Manufacturing System (FMS) is one in which there is some flexibility which allows the system to react to predicted, and unpredicted changes. The team investigated route flexibility, system capacity, flexibility of material handling systems, part flow, and the use of centralized computer controlled system such as the Mazak Flexible Manufacturing System for optimised part flow, job queuing, and transfers.
2.1 Protective Coating

While investigating possible methods to address slag buildup issues on the Mazak, literature was reviewed to seek ways similar companies had addressed the problem. A study was done by CNH Industrial on reducing the cost of cleaning their laser beds. CNH Industrial’s initial method of cleaning was a complete replacement of slats after intense slag build up. For the amount of cutting at CNH Industrial, the slat replacement costs were significant. A sister company, Fiat Industrial, implemented the coating on 19 machines over the course of three months. The study looked at the increased lifespan of the slats, and determined that cleaning costs could be reduced by up to 50%. Fiat Industrial decided to use the Weld-Rite Slat Guard because a respirator is required for the Slat Shield Plus. The Weld-Rite Slat Guard was also a better solution for protecting the slats because of the easy application, and the chemical has no smell or irritation values when applying. The slat guard turned the slag build up into powder which reduced the maintenance of the slats. Fiat concluded that the Weld-Rite Slat Guard was worth the investment. (Warner, 2016)

2.2 Manufacturing Layout

Another area for investigation was the design of the shop floor at Starflex. A flexible manufacturing system (FMS) is defined as a production method that is designed to easily adapt to changes in the type, and quantity of the product being manufactured. Machines are arranged in a manner to facilitate job flow by material handling systems such as AGVs, forklifts, loaders, etc. FMS can improve efficiency, and significantly lower production costs. Flexible manufacturing also facilitates make-to-order strategies that allow customer customization. Such flexibility can come with higher upfront costs for specialized equipment, and customization
(Sellitto, 2019). A plant can manufacture a variety of parts, and handle changing levels of production by computerizing, and configuring different machines with different interacting work stations, automated transfers, and storage systems, controlled by a distributed industrial computing system. Approved parts exit the FMS; rejected parts must return for further processing (Sellitto, 2019). Various types of parts can be processed simultaneously in various workstations that adjust themselves automatically to unexpected variations in the mix, and in the volume of the orders (Rose-Anderssen, 2017). “The simplest, and most flexible of FMS is a flexible machining cell” (FMC). It usually consists of one general-purpose CNC (Computer numerical control) machine tool interfaced with automated material handling which provides raw castings or semi-finished parts from an input buffer for machining, loads, and unloads the machine tool, and transports the finished workpiece to an output buffer for eventual removal to its next destination. An articulated arm, robot or pallet changer is sometimes used to load, and unload. Storage includes the raw castings area, the input, and output buffers” (Browne, J, 1984).

For high variety, and low volume, a combination of job-shop system, and discrete automation is better. For low variety, and large volumes, a combination of a flow-shop system, and transfer automation is better. Finally, in intermediate situations, a better solution combines cellular manufacturing, and FMS (Shivanand, 2006).

![Figure 1: Types of production automation](image-url)
There are five (5) types of layouts in an FMS (Shivanand, 2006):

1. Line type, where workstations are positioned sequentially, and allow a direct flow of material with loading, and unloading at separate extreme points.

2. Loop type, which allows the circulation of material to be loaded, and unloaded at the same point, and workstations are positioned in cellular, U-shaped format.

3. Ladder type layout, where the material circulates between, and around, is loaded, and unloaded at the same point by having workstations pairwise positioned.

4. Open field layout type, in which AGV freely moves across the workstations, transferring the material loaded, and unloaded at the same point.

5. Robot-centered layout type, in which the workstations are positioned around one or more robots, which allows any kind of movement of the material.

<table>
<thead>
<tr>
<th>S1[Ladder]</th>
<th>S2[Open Field]</th>
<th>S3[Robot Centered]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple orders executed simultaneously</td>
<td>More flexibility in processing parts</td>
<td>Low cost. High Return on investment</td>
</tr>
<tr>
<td>Low cost, mainly due to pneumatic devices</td>
<td>More accuracy due to forklift</td>
<td>More flexibility, and precision due to robots</td>
</tr>
<tr>
<td>Low set-up time due to the centralized tool magazine</td>
<td>Instant set-up due to individual magazines</td>
<td>Reduced set-up time due to the central tool magazine</td>
</tr>
</tbody>
</table>

Figure 2: *Advantages of different FMS layouts*

<table>
<thead>
<tr>
<th>Delays due to the single direction of the transport system</th>
<th>Excessive dependence on the forklift, and operator whose autonomy is limited</th>
<th>Small storage capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>More maintenance due to pneumatic system</td>
<td>Lower Reliability due to excessive dependence on AGV</td>
<td>Possible delays for the lack of availability of robots</td>
</tr>
<tr>
<td>Greater variability due to centralized tool magazine</td>
<td>Possible conflicts in loading, and unloading at same point.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: *Disadvantages of different FMS layouts*
Chapter 3: Current System Configuration

3.1 Loading & unloading

The Mazak laser is a critical component in the fabrication process, and as such, every minute the machine is not cutting is money lost to the company. The processes of loading, and unloading the machine bed are the primary areas of optimization as the cutting process cannot be accelerated. The loading process can vary in length from 1 to 5 minutes but the loading process is hard to optimize as it is dependent on operator preparation, and work order selection. Starflex deals with many different types of orders, and must be able to adapt to serve their customers’ needs. Currently, metal sheets are stored on a nearby shelf, and then dragged onto the bed. Heavier sheets are brought from the large storage area by forklift. The unloading process has been the largest contribution to machine down time. After the laser is finished with cutting a job, the cutouts must be removed, and sorted. Depending on the job, unloading can take from 2 to 15 minutes. A new loading process cannot begin until the bed is cleared. Every minute which can be saved yields improved throughput for the factory which allows for continued growth.

3.2 Cleaning & Maintenance

The bed of the Mazak laser is composed of more than 60 parallel metal cutouts with ridges, or slats. During the laser cutting, molten sheet metal, or slag, drips onto the bed, and hardens, causing buildup on the slats. This buildup results in the metal sheets not sitting properly on the bed, and interferes with the laser cutting. The machine must be cleaned weekly, and is reported to take up to 2½ hours to clean properly. Tools currently used in the slag removal process include a hammer, long pieces of metal, and sheer brute force. The current machine
maintenance does not include the preparation of the slats with a protective coating to prevent slag buildup.

The laser lens is critical to the cutting process, and will occasionally fog which causes ripples in the metal around cuts. When this happens, the lens must be removed, and cleaned, a process taking around 20 minutes, however this process may need to be repeated multiple times if cleaning was not sufficient. There is a replacement lens reserved for critical failures, but the complete housing for the laser lens has not been purchased.

3.3 Manufacturing Layout

The current layout of the manufacturing floor, and manufacturing systems is somewhere between manual methods, and programmable automation. The manual methods consists of operators queuing up individual jobs into the laser, loading, and unloading of the laser to begin the cutting process. The sheet cutting process is unmanned, and automated by the Mazak Laser. Starflex has a medium Routing Flexibility. The main method of transportation, loading, and unloading of the system is by forklift with multiple operators, and no designated routes, and no set priority for any of the work stations. There are a few designated pick up or drop off areas which are not enforced. Before the loading process, and after unloading process, the operator signals for transportation or transports the necessary parts if the wait time is longer than he deems necessary. Pallets containing finished jobs, and raw materials not moved by the operator or picked up from the workstation overflow into surrounding work areas.
Chapter 4: Data Collection and Analysis

4.1 Loading & Unloading

To determine how to optimize the load, and unload process, time trials needed to be collected, and analyzed. A camera was set up to record a standard work week from October 26 to November 1. From that footage, 36 independent load, and unload trials were observed. During the loading process, time would start when the operator selects a job, and continues until the operator had positioned the sheet correctly on the bed, and begins the cut. During the unloading process, time would start when the machine completes cutting, and ends when the last piece was removed from the bed, and the machine becomes available for a new job.

Based on the data, the average loading time was 1 minute 46 seconds with a standard deviation of 52 seconds. The minimum load time was 47 seconds, and maximum load time was 5 minutes. The average unloading time was 8 minutes 10 seconds with a standard deviation of 3 minutes 58 seconds. The minimum unloading time was 2 minutes 45 seconds, and maximum unloading time was 15 minutes 47 seconds. There was an average of 6 minutes, and 24 seconds difference between the loading, and unloading processes.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Unload</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>4:54:12</td>
<td>1:03:44</td>
</tr>
<tr>
<td>Trials</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Min</td>
<td>0:02:41</td>
<td>0:00:47</td>
</tr>
<tr>
<td>Max</td>
<td>0:15:47</td>
<td>0:05:00</td>
</tr>
<tr>
<td>Average</td>
<td>0:08:10</td>
<td>0:01:46</td>
</tr>
<tr>
<td>Std Dev</td>
<td>0:03:58</td>
<td>0:00:52</td>
</tr>
</tbody>
</table>

Table 1: Statistical Analysis Gathered from Video Analysis
Trial 18 unload; Time to complete 15:47. A necessary process for all jobs. Ties up the machine bed, physically demanding, time consuming.

Trial 20 unload, Time to complete 2:41. Fast. Sheets warp which could cause damage to parts.

The two pictures above are from the longest, and shortest trials. Trial 18 was a non-standard job with around 40 individually cut pieces each needing to be sorted out, and placed on corresponding pallets to be taken to the next station. This took multiple trips, and tied up the machine bed preventing a new job from being loaded. Trial 20 was also a non-standard job with around 200 individually cut pieces, each again needing to be removed from the sheet.
However, when the forklift removed the sheet from the bed, a new job could be loaded, and set to cut, then while the machine cuts, the operator can remove the cutouts from the previous sheet. Currently, the reason most jobs are not treated in the same manner is the warping of the sheet metal upon removal from the bed. In trial 20, the metal bows, however because there are so many parts, and each very small, and uniform, none of the pieces come loose or were damaged.

![Picture 3: Trial 34 Load; Time to complete 5:00. Operator needed to remove a sticker still affixed to metal. Prep work, and proximate shelving would decrease load-time.](image)

The picture above was from the longest of the loading trials. The forklift is required for nearly every load cycle. The few trials, most of which were under the average, where the forklift was not used, occurred when a sheet had been placed on the shelf near the machine by a forklift during machine cutting time of a prior job. Cycle time improvements can be realized by increase of proximate shelving to the Mazak laser as well as preparation of raw materials during the receiving process.
4.2 Cleaning & Maintenance

To determine the best way to optimize the cleaning process of the Mazak laser was to observe, and take time trials by hand. Time began when the operator began to take slats off the laser bed, and finished when the slats were put back on the laser bed, and the machine was ready to be used. After the time trial, interviewing the machine operator, and the plant engineer, the average time for slat cleaning was determined to be about 2½ hours. The greatest concern for those cleaning the slag off the slats was the amount of damage the slats endure during this process. Hammering the slats is not only a strain on the worker but also causes slats to be bent, and/or broken. Replacing broken slats because of the cleaning process will cause a halt in machine runtime for jobs using the laser in order to cut new slats.

Pictures 4-6 : Mazak Laser bed cleaning; Physically demanding, time consuming, non standard tools, damaging to the slats

The lens for the laser requires periodic cleaning due to fogging. The operator must take the lens casing out, which stops machine run time, go to a designated “clean” area to clean the lens, and return to put it back into the laser. This variability is due to the calibration process of the lens after the initial cleaning. If the lens is cleaned but does not test as ready to be used then the operator must go, and reclean or modify the housing on the lens.
Chapter 5: Proposed Process Implementations

5.1.1 Loading

The loading process is hard to optimize as it does not always have set pathways for transportation to the storage area, and back to the laser bed. In order to optimize this process, new shelves would need to be placed nearer the laser, and more effective sorting, and preparation of materials would need to occur before materials are placed onto shelves i.e. removal of labels, and residue. Currently, most sheets are transported directly from the large storage area to the laser bed to be loaded by forklift. Alternatively, the installation of a jib crane affixed to the nearby column would allow the operator to transport sheets from the shelves to the machine without the use of a forklift. (Refer to Appendix C: Mazak Laser Area) This, along with a vacuum lifter attachment, would allow the operator to quickly grab a sheet from the top of a stack, and transport it to the laser bed. Operator time can also be optimized by using laser cutting time to move material for the next job(s) to shelving nearest the Mazak, reducing load time to approximately 1 minute per job potentially reducing load time by 50%, and overall cycle time by 2.5%.

Pictures 7-8: A column mounted jib crane, and a sheet vacuum lifter meant to help the operator move sheets from storage to the laser bed. The jib crane cannot be used during unloading as the vacuum cups need a good seal without cuts beneath the cups.

(Vestil, 2006) (Acculift, 2018)
5.1.2 Unloading

The current unloading process occupies the laser bed for several minutes, preventing the initiation of a new work order. The proposal is to unload the cut sheet off of the laser bed intact, and move the sheet to a nearby area for cutout removal. This will allow a new sheet to be loaded onto the bed, and the cutting process started on the next job. The operator can then remove the cutouts from the previous job while the laser cuts, without having valuable time lost. This proposal will reduce unloading time to a comparable level to the loading times, saving an average of 6 minutes per job. This should increase the efficiency of unloading by 75%, and overall cycle time by 15%.

To facilitate the unloading of the cut sheets, several methods were investigated, and analyzed. The first method is to use a single/double/triple pallet attachment for a forklift to lift the sheets off the machine. A pallet attachment features 3 pairs of forks, evenly spaced to allow the movement of 3 pallets at the same time. The 6 tynes should allow the forklift to lift the sheet off of the machine without allowing it to warp, which could cause cutouts to fall out. The forklift could then move the cutouts to a separate area where the operator can sort the pieces during the next cutting job.

![Picture 9: Single/Double/Triple Forklift attachment; Tynes can be spaced to allow larger loads to be picked up; still has spaces between forks that could cause parts to fall.](Cascade, 2019)
The ideal method is to use an automated load/unloader cell, designed by Mazak, to unload the machine after a work order is completed. The cell would slide a tray under the completed work order, and move it to a nearby area for unloading. The cell would need to be mounted on a bridge crane, and would take up 4 times as much shop space as the current laser bed. The complete cycle of unloading the cut sheet, and reloading a new sheet takes 2½ minutes, however, sheets must be prepared in loading area so additional prep times are required. This solution would create an increase of 70% in the load/unload cycle, and gain a 17.5% in overall cycle time.

Picture 10: Mazak Load/Unload Machine; Vacuum lifts a replacement sheet, then slides bars between slats to lift job from bed, places new sheet on the bed, then moves cut job to area to be unloaded, and sorted; fast, automated load unload; large footprint/price tag, hands off process, requires additional preparation to be optimal. (Storik, 2016)
5.2.1 Weekly Slat Cleaning

The proposal is to implement the use of a protective coating, and to purchase more effective tools to ease the cleaning process. The protective coating must be applied to new or cleaned slats to be effective. The slats should show increased life span, and will be far easier to clean. A complete machine refit with new slats that have been sprayed with a protective coating is suggested to show the best results. It is expected that the refit would need to be done twice per year based on the study.

Two methods of improved cleaning tools were identified. The first is the purchase of a heavy duty slat cleaning machine, such as the TruTool TSC or SlagHog. These machines can cut through heavy slag that builds up when lasers are run continuously. The expense of these machines are outweighed by their portability, and efficiency when used on multiple continuously running automated lasers.

The second method, considered the most cost effective, is to purchase a pneumatic air chisel, and an industrial steel brush that would also help in the cleaning process. The air chisel can apply the force needed to remove the slag with more precision, and it is possible to quickly remove slag by wedging the chisel between the slat teeth, causing the slat to vibrate, and the slag to fall off. This will also be augmented by sturdier tools, and brushes to help reduce cleaning times. Either of these improvements have the potential of reducing weekly cleaning time to the recommended biweekly cleaning of 30 minutes, as opposed to the current 2½ hours per week, creating an additional 1½ hours of production time weekly. These improvements should cause an increase in shop efficiency of 4% per week.
5.2.2 Lens Rotation

The implementation of a lens rotation, where once a lens is in need of cleaning, the lens is replaced by a previously cleaned lens, and operations allowed to continue, would need a second complete housing in order for the swap to be seamless. The operator would then be able to clean the lens while the machine continues to run, preventing a possible down time of 20 minutes or up to 60 minutes. For analysis, an average of 40 minutes per cleaning was used. The lens does not have a clear mean time to failure, but based on the time study, and the machine maintenance log, the lens needs cleaning once per week. It is suggested that a third lens, and a complete lens housing be purchased, allowing the housing to cycle into the machine, and an additional lens in reserve in the case of a double critical failure. This improvement will give an increase in machine efficiency of 2% per week.

Picture 11: A laser lens housing, and the individual parts inside the housing. In order to rotate lens, a full housing is needed as the process of taking apart the housing is the longest part of the cleaning process.

(Lens Savers, 2014)
5.3 Manufacturing Layout

For the first alternative, Starflex will consider a ladder-type layout. Transportation is done by pallets, and conveyors in a single direction. Machine will be fed, and unloaded by designed pneumatic devices with loading, and unloading done at different points. Proposed is an automated inspection of the CNC machine, a central tool magazine, supported by a temporary storage area with capacity for four hours of production. The sequencing, and control are to be done by one operator.

The second alternative would be an open-field layout. The transportation will be done by forklifts manned by one operator, with free movement, and containers at the various stations. A forklift will feed, and remove material from the machines, and the loading, and unloading of materials to, and from the system occur at the same point which will be standardized. Stations will have individual tool magazines, supported by a carousel temporary storage area with capacity for eight hours of production. The Mazak Laser Cutter will be manned by one operator.

Considering the third alternative, Starflex examines the open loop layout with an automatic loader, and unloader system designated for the laser cutter. With a loop-centered layout, the transportation to the workstation can be done using the existing forklifts. This will allow forklift route optimization. The automatic loader will have 5 shelf storage, and containers with free movement. The loader will feed, and remove material from the laser cutter by using arms, and picking up from pallets, and placing on the laser bed. The loading, and unloading of materials to, and from the system will occur at the same point. The Mazak FMS transports, positions, cuts, and stacks the finished material automatically. It can run unattended, and move from one nest to another. It can also select materials, and thickness without new setups. This
solution optimizes the nesting process of the laser cutter, saving on materials. Nesting drawing data, and desired quantity cutting time can be sent to the FMS machine controller automatically by the Mazak Smart System. Nesting drawing, and parts drawing can be shown on the controller. Office PCs can be connected directly to FMS machine controller via computer network. This versatility can optimize production scheduling, and job assignment. (FMS For Laser Processing Machine, 2019)

It was determined that the loop style flexible manufacturing system layout was the most effective, and ideal solution at improving material flow issues at the shop. A designated pick up, and drop off point would be enforced, and one route will be maintained in a loop style following product flow. This layout will allow for easy integration with the Mazak FMS, and Smart Center.
Chapter 6: Cost Benefit Analysis

6.1 Costs

6.1.1 Loading

For the proposed changes to the loading of the laser bed, additional shelving, adjacent to the Mazak laser, would need to be installed. It was determined, during observation, that the fastest load times occur when material for the next job is located on shelves near the machine. Design of additional shelving units would need to be determined in consult with the Mazak operator(s), and the shop foreman, and bids solicited to implement this addition. Research indicates that the units would cost between $400 to $2,000 depending on customizations. The Jib crane was estimated around $2,000, and the vacuum lifter attachment was estimated at $10,000. Installation of these products would take additional costs that could not be forecast.

6.1.2 Unloading

The costs of the proposed unloading systems were difficult to price due to customization. The single/double/triple pallet forklift attachment is available for lease at $656 per month or for purchase between $10,000 to $20,000. The sorting area will be customized to suit the needs of the operator, but it is estimated to cost $1,000 to $3,000. Alternatively, the Mazak unloading system was not priced based on a system of unloading only but was priced based on the complete automated load unload system. The loading of the sheet into the prep area would still need to occur before each cycle could begin. This system would cost up to $900,000. The design of the system also takes up 4x more shop space than the current Mazak laser bed. This is due to the need to cage around the load/unload machine to prevent accidents.
6.1.3 Cleaning & Maintenance

Costs were gathered from various online sources, and not on specific quotes from any company. Based on the research, a complete machine refit would cost between $500 to $600, and can be completed in approximately 4 hours. Currently, Starflex does a complete machine refit four times per year, and improvements should reduce this to two times per year. Implementation of the protective coating requires the purchase of an industrial sprayer along with additional safety equipment estimated at $500 with an additional annual purchase of a 5 gallon container of Weld Rite Slat Guard at $150. It takes approximately 10 minutes to spray the bed, and is suggested to be reapplied after 4 weeks. An air chisel can run between $50 to $100, and air is already available throughout the shop. Metal brushes, sturdier tools, and chisels were budgeted at another $100. It was assumed these tools would need to be replaced every year. An additional laser lens housing would cost $6,500, and additional lens would cost $600, and would only need to be purchased once as the lenses are not prone to critical failure.

<table>
<thead>
<tr>
<th>Costs</th>
<th>Current Year (CY)</th>
<th>CY +1</th>
<th>CY +2</th>
<th>CY +3</th>
<th>CY +4</th>
<th>CY +5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost to Implement Loading Improvements (Jib/Vacuum/Shelves)</td>
<td>$14,000.00</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Cost of Forklift Attachment</td>
<td>$15,000.00</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Cost of Mazak Load/Unload Machine</td>
<td>$900,000.00</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Cost to Implement Slat Guard (Equipment/Chemicals)</td>
<td>$650.00</td>
<td>$150.00</td>
<td>$150.00</td>
<td>$150.00</td>
<td>$150.00</td>
<td>$150.00</td>
</tr>
<tr>
<td>Cost of Manual Cleaning Tools (Air chisel/brushes)</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$200.00</td>
</tr>
<tr>
<td>Cost of Cleaning Machines</td>
<td>$7,000.00</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Cost of Laser Lens and Housing</td>
<td>$7,100.00</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
</tbody>
</table>

Table 2: Cost Analysis based on Estimations of Comparable Products
6.2 Benefits

6.2.1 Loading

The proposed installation of a jib crane, vacuum lifter, and additional proximate shelving would reduce forklift usage, reduce operator strain, and allow a single operator to load jobs. This has the potential to decrease load time to 1 minute per job, or a 50% reduction in load time, and a 2.5% reduction in cycle time. Other benefits are difficult to quantify without further implementation.

6.2.2 Unloading

The purchase of the Mazak load/unload cell was examined. The unit, based on video demos, has a total load/unload time of approximately 3 minutes. This compares to current load/unload time averaging 10 minutes. This would increase efficiency by 70%, and cycle time by 17.5%.

Alternatively, the lease/purchase of the Single/Double/Triple pallet forklift attachment, and an area for sorting has the potential to reduce unloading times to be comparable to the current loading times, saving 6½ minutes per job. This will decrease unload times by 75%, and cycle time by 15%.

6.2.3 Cleaning & Maintenance

The cleaning time reduction was determined based on a study done for the protective coating, and various laser bed cleaning tutorials. Current methods increase the risk of operator strain or injury, and sometimes result in damage to slats, increasing the necessity for machine refits. It is expected, with the use of a protective coating, and improvements to cleaning tools,
cleaning time should be reduced to 30 minutes twice per week. This should reduce refits from 4 per year to 2 per year, decrease cleaning time by 60%, and increase production availability by 4%. The implementation of a rotating laser lens, and housing is expected to save 40 minutes every week. The rotating lens would also reduce the wear on each individual lens. This has the potential to increase production availability by 2%.

Table 3: Benefits Analysis based on Expected Time Added, and a $60/hr operating cost

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Current Year (CY)</th>
<th>CY +1</th>
<th>CY +2</th>
<th>CY +3</th>
<th>CY +4</th>
<th>CY +5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving on Loading Times (Job/Vacuum/Shelves) 1 min/job</td>
<td>$1,872.00</td>
<td>$1,872.00</td>
<td>$1,872.00</td>
<td>$1,872.00</td>
<td>$1,872.00</td>
<td>$1,872.00</td>
</tr>
<tr>
<td>Savings on Unloading Time (Mazak load/unload cell or Forklift Attachment) 6.5 mins/job</td>
<td>$13,520.00</td>
<td>$13,520.00</td>
<td>$13,520.00</td>
<td>$13,520.00</td>
<td>$13,520.00</td>
<td>$13,520.00</td>
</tr>
<tr>
<td>Savings on Cleaning Time (Protective Coating/Improved Tools) 1.5 hours/week</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
</tr>
<tr>
<td>Savings on Refits due to Improved Cleaning (4/year vs. 2/year)</td>
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<td>$1,200.00</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
</tr>
<tr>
<td>Savings on Lens Rotation (Housing/Lens) 40 min/week</td>
<td>$2,080.00</td>
<td>$2,080.00</td>
<td>$2,080.00</td>
<td>$2,080.00</td>
<td>$2,080.00</td>
<td>$2,080.00</td>
</tr>
</tbody>
</table>
6.3 Cost Benefit Comparisons

The net benefits were analyzed to a 6 year forecast based on the costs versus the maximum dollar saved for each solution. A $60/hour shop cost was used.

6.3.1 Loading

In examining the potential benefit of the jib crane, vacuum lifter, and shelving in the loading process, the cost recovery would take more than seven years. However, the ergonomic benefits, possible injury reduction, and operator efficiency improvements are difficult to quantify.

<table>
<thead>
<tr>
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<tbody>
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<tr>
<td>Total PV Costs</td>
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<tr>
<td><strong>NET BENEFIT</strong></td>
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</table>

Table 4: Net Benefits of Loading Solution (Jib Crane/Vacuum Lifter/Shelving)

6.3.2 Unloading

Two systems were examined that would increase efficiency of the unloading process or actually the load/unload cycle in the case of the Mazak cell. Based on a $60/hour shop cost it would take more than sixty years of standard operation to recoup the expense. These machines become more cost efficient when they can be run continuously on a 24 hour cycle. Alternatively, implementing the single/double/triple attachment to a forklift, and utilizing a separate sorting area is the most cost-effective solution. A test-run of leased equipment with the attachment is suggested to determine the viability of the solution before purchasing for cost efficiency.

<table>
<thead>
<tr>
<th>Cost Benefit Analysis</th>
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<tbody>
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<tr>
<td>Total PV Costs</td>
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<tr>
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</table>

<table>
<thead>
<tr>
<th>Cost Benefit Analysis</th>
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<tbody>
<tr>
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<td>$ 68,954.67</td>
</tr>
<tr>
<td>Total PV Costs</td>
<td>$ 15,000.00</td>
</tr>
<tr>
<td><strong>NET BENEFIT</strong></td>
<td><strong>53,954.67</strong></td>
</tr>
</tbody>
</table>

Table 5-6: Net Benefits of Implementing Unloading Solutions

(Mazak Cell vs. Forklift Attachment)
6.3.3 Cleaning & Maintenance

Manual versus machine cleaning solutions were examined to decrease laser bed maintenance time, and increase operational availability. In both cases, the time-saving benefits are projected to be the same. Cost of cleaning machines is approximately four times more expensive than the cost of the manual cleaning tools. The implementation of a protective coating should reduce the need for machine refit to semi-annually. This will save $1000 to $1200, and 8 hours of machine down-time, allowing for 8 hours additional production time annually.

Table 7-8: Net Benefits of Implementing Cleaning Tools Solutions

(Slat Cleaning Machine vs. Manual Tools)

Lastly, implementing a lens rotation with additional housing was analyzed. This solution has cost recovery of less than 4 years. The benefit of decreased lens wear was difficult to estimate, but it should increase lens life by around 50%.

Table 9: Net Benefits of Implementing Lens Rotation (Housing/Lens)
Chapter 7: Conclusions

Based on the analyses, the first implementation suggestion is to decrease cleaning time through the use of the protective coating, and manual cleaning tools, as it has a seven times greater benefit to upfront cost ratio. For an investment as small as $850, first year benefits are nearly $6,000. If the shop has plans for future purchases of additional lasers or the integration of automatic loaders, the slat cleaning machine would be more effective as it has increased portability, and utility compared to manual tools. The second implementation suggestion is to decrease unload time through the use of the single/double/triple pallet forklift attachment as it has a 1½ times greater benefit to cost ratio, but requires a larger upfront cost if a full attachment were to be purchased.

In the future, a system of lens rotation could be implemented as it can also become profitable within a four year term. Installation of the jib crane/vacuum lifter/proximate shelving can also be examined as it has other benefits that may increase shop efficiency in the long run, although cost recovery is not until year seven. Finally, the complete Mazak load/unload cell is not suggested in the current shop configuration as it has very large upfront, and maintenance costs as well as a large shop footprint, and requires shop redesign.
Appendix A: Acknowledgements

Senior Design Project Professor:
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Contact Assistance:
JR Smith (Operations Manager, Starflex Fabrication)

Workplace Assistance:
Jeff Sterling (Quality Manager, Starflex Fabrication),
Jason Hamrick (Engineer, Starflex Fabrication), and
Dennis Garner (Plant Manager, Starflex Fabrication)

Paper editing:
KSU Writing Center Staff; Lisa Palm

Programs used in Project:
Wyze Camera; Wondershare Filmora 9; Microsoft Office: Word, Excel, and Visio;
Google Office: Docs, Slides, and Sheets; TwistedWave Audio Editor;
Video downloadhelper addon

Video Soundtrack:
Crystallize by Lyndsey Sterling
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Email: Terrilianoji@yahoo.com
Phone: (405) 588-2903
Appendix C

Gantt Chart

Mazak Laser Shop Area

(Not to scale)

Mazak laser area
Cost Benefit Analysis

<table>
<thead>
<tr>
<th>Costs</th>
<th>Current Year (CY)</th>
<th>CY +1</th>
<th>CY +2</th>
<th>CY +3</th>
<th>CY +4</th>
<th>CY +5</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Cost of Forklift Attachment</td>
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<tr>
<td>Cost of Manual Clearing Tools (Air Dust/Brushes)</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$200.00</td>
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<tr>
<td>Cost of Lens Lense and Housing</td>
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Benefits

<table>
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<tr>
<th>Benefits</th>
<th>Current Year (CY)</th>
<th>CY +1</th>
<th>CY +2</th>
<th>CY +3</th>
<th>CY +4</th>
<th>CY +5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving on Loading Times (Lift/Vacuum/Shelves) 1 min/job</td>
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<td>$1,872.00</td>
<td>$1,872.00</td>
<td>$1,872.00</td>
</tr>
<tr>
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<td>$13,520.00</td>
<td>$13,520.00</td>
<td>$13,520.00</td>
<td>$13,520.00</td>
</tr>
<tr>
<td>Saving on Cleaning Time (Protective Coating/Improved Tools) 1.5 hours/week</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
<td>$4,680.00</td>
</tr>
<tr>
<td>Savings on Refills due to Improved Cleaning (4/year vs. 2/year)</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
<td>$1,200.00</td>
</tr>
<tr>
<td>Savings on Lens Rotation (Housing/Lens) 40 min/week</td>
<td>$2,080.00</td>
<td>$2,080.00</td>
<td>$2,080.00</td>
<td>$2,080.00</td>
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</tr>
<tr>
<td>Total Benefits (Future Value)</td>
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<td>$23,352.00</td>
<td>$23,352.00</td>
<td>$23,352.00</td>
<td>$23,352.00</td>
<td>$23,352.00</td>
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Single/Double/Triple Forklift Attachment (Cascade, 2019)
Report from CNH Productions covering Weld Rite Slat Guard

Pugh Matrix

Load/Unload

<table>
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<tr>
<th>Criteria</th>
<th>Weights</th>
<th>Industry Standard</th>
<th>Current System</th>
<th>Crane</th>
<th>Crane+Vacuum</th>
<th>Forklift Attachment</th>
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<tbody>
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<td>-2</td>
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<td>-1</td>
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</tr>
<tr>
<td>Impact on Unloading</td>
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<td>-2</td>
<td>-2</td>
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<td>2</td>
<td>-2</td>
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<td>1</td>
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<td>44</td>
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</table>

Cleaning Bed

<table>
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<tr>
<th>Criteria</th>
<th>Weights</th>
<th>Industry Standard</th>
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<td>-2</td>
<td>1</td>
</tr>
<tr>
<td>Cost</td>
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<tr>
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<td>-2</td>
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<td>Worker’s Strain</td>
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References


